PERSPECTIVE

The Saga of Genetically-Modified (GM) and Herbicide-Tolerant (HT) Crops in India

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Abstract

This essay is a personal opinion on India's struggles with the regulatory management of technologies involving genetically-modified organisms (GMOs). I intend to provide an analytical viewpoint relevant to India, based on my own experience, both as a weed scientist and a former Research Director.

Approved in 2002, insect-resistant Bt cotton[2](*Gossypium hirsutum* L.) is the only genetically-modified (GM) crop that is currently being grown in India. Bt cotton technology is considered a success story, which catapulted India into the second-largest cotton producer globally with additional benefits of enhanced farmer's income and decreased pesticide use. The opponents of GM technology, however, have a different story to tell. Since then, there have been many attempts to introduce other GM crops, notably with insect-resistant and herbicide-tolerant (HT) traits. Despite years of successful regulatory trials and approval by the highest regulatory body, Bt brinjal (*Solanum melongena* L.) and HT mustard (*Brassica juncea* (L.) Czern.) technologies were put on hold by the Government, owing to the strong opposition by the anti-GM Lobby.

The Government's inability to develop a sound national policy on GMOs and its weakness to deal firmly with activists opposing GM technology are sending the wrong signals. They scuttle innovation, introduce an element of doubting science, prevent access to advanced technologies and private investments. On a more practical note, the indifference and the inordinate delay in Government's action are resulting in large scale illegal cultivation of herbicide-tolerant Bt cotton (HTBt cotton) in several states for the last 4-5 years. There have been widespread protests by farmers and farmer groups demanding access to GM technology. The Government is trying to regulate the use of herbicide glyphosate to stem the illegal cultivation of HTBt cotton. The move will have an adverse impact as it will deprive farmers of a herbicide, which is hugely popular and has the largest market share. It is to be seen what the Government will do with the illegal cultivation of HTBt cotton. Will it go the Bt cotton way? Unable to find a solution to the illicit trade of and unauthorized cultivation of GM cotton, the Government gave official approval for Bt cotton in 2002. Will history repeat itself is a million-dollar question.

Keywords: GM crops, Bt cotton, Bt brinjal, GM mustard, Herbicide tolerant crops, HTBt cotton

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[2] Strains of the bacterium *Bacillus thuringiensis* produce over 200 different *Bt* toxins, harmful to different insects. Most notably, *Bt* toxins are insecticidal to the larvae of moths, butterflies, beetles, cotton bollworms, but are harmless to other forms of life. The gene coding for Bt toxin has been inserted into cottoncausing it to produce this natural insecticide in its tissues. In many regions, the main pests in commercial cotton are lepidopteran larvae, which are killed by the *Bt* protein in the GM cotton they eat. This eliminates the need to use large amounts of broad-spectrum insecticides to kill lepidopteran pests (some of which have developed resistance to insecticides).

Introduction

It was a dream come true for a budding weed scientist like me to do his Ph.D. research work at Weed Research Organization (WRO), Oxford, UK. Sadly, closed now, it was then considered as the 'Mecca' for weed scientists. It was an exhilarating experience to appreciate and use the sophisticated facilities, interacting with highly competent staff and a rare opportunity for interactions with weed scientists from around the world who visited WRO for short term research work on sabbatical.

Armed with better knowledge and competence in weed science, I returned to the Indian Agricultural Research Institute (IARI) at New Delhi in 1985 to continue my engagement in research and teaching weed science, which went on for over next 15 years until I took up the position of Director, *National Research Centre for Weed Science*, at Jabalpur - now renamed *Directorate of Weed Research* (DWR).

The selective action of herbicides fascinated me from early days, and I hoped that the herbicides would offer a better alternative to manual weeding and would provide relief to millions of farm women and children who spend a good part of their life pulling weeds. Born to a farming family and on a small farm, I have first-hand experience pulling out weeds in rice, apart from familiarity with other agricultural operations. The experience of doing weed control chores in rice, in deep water, with rains showing no mercy on us, was an experience to remember.

As a prelude to the paper's main topic, I provide some insights into the development of weed science as a discipline in India.

Weed Science in India

Systematic research on weed management in India was initiated in 1952 with the inception of *All India Coordinated Research Scheme* on significant crops, such as rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.) and sugarcane (*Saccharum officinarum* L.). In the same year, the weed control section was initiated in the Division of Agronomy at the Indian Agriculture Research Institute (IARI) at New Delhi.

The group was headed by Professor V. S. Mani, with whom I had the privilege of working during my initial years of service at the IARI. The launching of the All India Coordinated Research Project (AICRP) on Weed Control 1978, with centres in many parts of the country, could be termed as a historical development. Weed research in India got further boosted with the establishment of the *National Centre for Weed Science* (NRC-WS) at Jabalpur, Madhya Pradesh, in 1989, which was upgraded as the *Directorate of Weed Science Research* (DWSR) in 2009. The institute was renamed the *Directorate of Weed Research* in 2014 (DWR,2015). Since its inception, the institute has engaged in basic and strategic research on weeds and weed management (DWR, 2014). It also coordinates location-specific weed research under the AICRP-WM, currently operating at 17 centres with six volunteer centres located in different parts of the country [3].

As the Director of the NRC-WS, from 2000 to 2005, I strengthened and streamlined the research and training activities. Besides, all the State Agricultural Universities, currently numbering over 50, offer research and teaching activities in weed science and are responsible for developing weed management recommendations for areas under their jurisdiction. These institutions have done a commendable job in creating awareness among Indian farmers about the importance of weeds and their management in enhancing crop productivity.

The Indian Society of Weed Science (ISWS), established in 1968, with its official publication - *Indian Journal of Weed Science*, and in hosting regular meetings and conferences is also contributing its might in promoting weed science in the country. It was indeed a proud moment for me, as President of ISWS and the Asian-Pacific Weed Science Society (APWSS), when India successfully organised the 25th Silver Jubilee APWSS Conference in 2015 at Hyderabad. I am happy to add that with over 700 participants, it was the largest conference held so far in the history of APWSS.

The beginning of Chemical Weed Control

After decades of efforts by several Indian organisations in the 1960s, farmers began to appreciate weeds as an essential production constraint. Herbicides began to be used to manage weeds effectively, but herbicide use was limited in the initial years due to the high cost of chemicals. Most herbicides used to be imported, and there was inadequate technical know-how of their use.

[3] Source: **https://dwr.icar.gov.in/AICRP-WM-Centers.aspx**.

Policymakers also did not favour herbicides as they believed that India had plenty of cheap labour.

The introduction and large-scale cultivation of short duration and dwarf cultivars of wheat and rice in the 1960s led to the much-talked green revolution in the country. The adoption of these cultivars, which were responsive to high inputs, led to drastic changes in the cropping pattern and the production practices. These changes led to the evolution of several problems, which were not perceived before.

Increased infestations of grass weeds, such as littleseed canary grass (*Phalaris minor* Retz*)* and wild oats (*Avena sterilis* ssp*. Ludoviciana* (Durieu), in wheat, were one such negative impact of the green revolution. Close planting of the crop and morphological similarities of the weeds with the crop proved a big challenge for effective and timely control through mechanical and manual methods. Of the two, *P. minor* was (and still is) the more predominant one.

The use of crop seeds, contaminated with weed seeds, and wheat harvesting using combine harvesters, which are custom-hired and travelled long distances - aided in infesting newer areas. Its severity has been exceptionally high in the rice-wheat system, the most predominant cropping system in an area of >10.0 million hectares (Mha). In less than 5-10 years, *P. minor* became the number one 'pest' of wheat over a large swath of the Indo-Gangetic belt (Figure 1).

***Figure 1 A wheat crop heavily infested with littleseed canary grass (Phalaris minor*)**

Populations ranging from 1000 to 2000 plants/m^2 infested some areas, compelling many farmers to harvest the crop prematurely as animal feed or plough down the crop to make way for planting an alternate summer crop like sunflower (*Helianthus annus* L.). Weed scientists at the IARI, New Delhi and the SAUs in Punjab, Haryana and Uttar Pradesh intensified their research on herbicides against these grass weeds. With the problem reaching its peak and increased complaints by the farmers, experts from overseas were invited to assess the situation and suggest control measures. Professor John Fryer, former Director of WRO, Oxford, was one such expert. I had the privilege of travelling with him to some of the problem areas.

After consultation with Indian counterparts, the experts recommended the use of herbicides to stop the further spread of weeds and to reduce the yield losses. After extensive research, herbicides, such as methabenzthizuron, chlortoluron, metoxuron and isoproturon [4], proved effective in selective control of wild oats and *P. minor* in wheat. Agrochemical companies responded swiftly by making the herbicides available within a short period by importing them, and later, by producing them indigenously.

Among these herbicides, isoproturon, became a clear favourite with the farmers and was adopted widely and quickly. Besides grass weeds, isoproturon gave good control of other major broadleaved weeds found in wheat. It remained a reliable chemical for many years until the development of resistance in *P. minor* in the early 1990s. In retrospect, it is evident that the grass weed problem triggered by the large-scale cultivation of Mexican dwarf wheat marked the beginning of the large-scale use of herbicides in the country. Soon, herbicides became the principal method of weed management in wheat in North-Western parts of India, where labour was expensive, as the migrant labourers carried out most agricultural operations. Looking at the success in wheat, more and more farmers adopted herbicides in other crops and other areas.

Currently, it is estimated that herbicides are being used in India on more than 20 million ha, which constitutes about 12% of the total cropped area in the country (Sharma et al. 2018). The pesticide market in India is relatively small (about USD 1 billion) compared to the global market (USD 33 billion). The share of herbicides is nearly 18% of the total pesticides used and is expected to grow further and faster. Although herbicides have been in use for over three decades, usage has increased only recently. Wheat, rice, soybean [*Glycine max* (L.) Merr.] and sugarcane are the major crops where herbicides are in use with approximate shares of 28, 20, 9 and 7%, respectively [5].

[4] Table 1 at the end of the essay provides the chemical names of the herbicides.

[5] The list of herbicides approved and used in India is available at **http://cibrc.nic.in/mup.htm**.

Brush with Herbicide resistance

Although Indian weed scientists were aware that the continuous use of a single herbicide would lead to the development of resistance in weeds, the first report of resistance, recorded in *P. minor* to isoproturon in wheat, came in the early 1990s (Malik and Singh 1993). The finding caught the scientific community by surprise. It was least expected that the continuous use of the herbicide within a relatively short period of 8-10 years would result in the development of resistance.

R. K. Malik and his team were the first to observe resistant populations of *P. minor* in the Haryana State. Dr. Malik then asked me to check for resistance to make sure that it was indeed a case of herbicide resistance. While it took some time for weed scientists to understand the situation, the problem spread quickly and covered over a million ha in less than five years. Unaware of the resistance development in the weed, farmers resorted to repeated applications of isoproturon, often at higher doses, hoping for reasonable levels of *P. minor* control. I have the first-hand experience of the situation, as I travelled extensively in Punjab and Haryana, collecting *P. minor* seeds from hundreds of fields for research at the IARI.

The situation was reminiscent of what farmers experienced in the pre-herbicide era, during the early 1970s. It presented a threat to the food security of the country, as this region was (and still is) considered as the 'food bowl' of India. Scientists swung into action and began testing new herbicides. The Government of India, too, took cognisance of the situation and enabled priority registration of new herbicides. Among the new molecules, clodinafop, fluazifop-butyl and sulfosulfuron were found effective and were recommended in 1997-98 for controlling the resistant population of *P. minor*.

Despite their higher cost, farmers soon started using the new chemicals, as it was a simple choice between a good crop or total crop failure. The new herbicides brought the resistant *P. minor* infestations under control and restored yields to their previous levels. However, the 'success was short-lived. The alternate herbicides, with their higher propensity for development of resistance, led to increased instances of cross- and multiple-resistance. Currently, *P. minor* is being controlled using a limited number of herbicides, applied either sequentially or as mixtures. Pre-emergence applications of pendimethalin or pyroxasulfone; or post-emergence applications of clodinofop, pinoxadem, sulfosulfuron, or various combinations of clodinofop and metribuzin, sulfosulfuron and metsulfuron or mesosulfuron and iodosulfuron, are currently recommended (Kaur et al., 2020; Punia et al., 2020).

With the choice of herbicides with different modes of action (MoA) being limited, and the farmers' reluctance in doing away with rice-wheat rotation or use of other non-chemical approaches, the problem of *P. minor* is far from over. The experience of herbicide resistance in *P. minor* has made the weed technologists much wiser than before. Except for one more weed, toothed dock (*Rumex dentatus* L.), which has been reported to have developed resistance to some ALS inhibitor herbicides [6] used in wheat (Heap, 2021), no other instance of herbicide resistance has been noticed so far.

GM Crops in India

During this period, I watched closely and with a great deal of interest the development of GM herbicide-tolerant (HT) crops and their popularity in other parts of the world. It was quite natural to appreciate that a non-selective herbicide, such as glyphosate, could be applied to control a broad spectrum of weeds without worrying about the toxicity to the crop. I, too, was impressed with the merits of the technology. Despite the negative campaigning by the anti-GM groups, the technology found large-scale adoption globally within a short time. With the expectation that the technology would help our farmers, Indian weed scientists also started talking about favouring herbicide-tolerant crop technology.

As the then Director of the ICAR-DWR, I organised the first meeting to brainstorm the relevance of the HT crop technology to our farmers back in August 2005. A second meeting followed, under the auspices of ISWS, in 2016. On both occasions, the weed scientists and others who participated overwhelmingly supported the introduction of the HTC technology.

Bt cotton is the only GM crop approved for commercial cultivation in India. The technology has been developed by the Maharashtra Hybrid Seeds Company (Mahyco) - an Indian company, in technical collaboration with Monsanto (Choudhary and Gaur, 2015). Cotton is an important commercial crop in India, and before Bt cotton, the farmers used to incur

[6] Herbicides that inhibit acetolactate synthase (ALS), a key enzyme in the biosynthesis of the branched-chain amino acids isoleucine, leucine, and valine. Examples are herbicides belonging to imidazolinone and sulfonylurea groups.

yield losses to the tune of 30-35% due to infestation of bollworms. The most dominant and destructive being the American bollworm (*Helicoverpa armigera* Hubner). Controlling this pest required a minimum of 6–8 applications of insecticides, mainly pyrethroids, of which some became ineffective due to resistance development in bollworms.

Cotton used to be the major user of pesticides accounting for 46% of total insecticide used in Indian agriculture. The insect-resistant *Bt* cotton varieties expressing novel cry gene(s) were approved for commercial cultivation in 2002. In a short period of 10 years, around 7.2 million small cotton farmers representing more than 90% of total cotton farmers in the country adopted *Bt* cotton (Figure 2). The technology was hailed as a big success story, which propelled India to be a major cotton-producing nation globally. It is reported to have increased the crop yields by 23-43% and farmers profits by 50-130% (Choudharyand Gaur, 2015). Since its introduction, *Bt* cotton has been estimated to have added INR 315 billion (USD 7.2 billion) to national income with 40-60% reduced pesticide use, amounting to INR 11 billion (USD 0.15 billion).

***Figure 2** Luxurious growth of Bt cotton in a farmer's field, the only GM crop commercially approved for cultivation in India*

The introduction and commercialization of *Bt* cotton have not been without objections. Besides the usual concerns, *Bt* cotton has been alleged to cause sheep and cattle deaths following the animals feeding on *Bt* cotton foliage, decrease in soil fertility, adverse human health issues, and to some extent, caused farmers' suicides. Even after nearly 20 years, the controversy has not died down.

Bt Brinjal

Following the success of *Bt* cotton, the Mahyco, in collaboration with Indian public research institutions, developed an insect-resistant brinjal (Aubergine or eggplant) using the *Bt* gene. Brinjal is a high-value vegetable crop that is widely grown and consumed in India. The crop is highly vulnerable to fruit and shoot borer (*Leucinodes orbanalis* Guenee).

In response, farmers spray the crop heavily and repeatedly with highly toxic pesticides but with limited success. After eight years of successful trials and submission of the required data, the Genetic Engineering Approval Committee (GEAC) - the highest statutory body for approval of GMOs in the country, approved *Bt* brinjal for commercial cultivation in 2009 (Figure 3).

***Figure 3** Bt brinjal in an open field trial. Despite the recommendation for commercial cultivation in 2009, the Government, under pressure from the anti-GM lobby, is yet to give final approval*

As expected, the anti-GM Lobby came down heavily, and this time the protests were larger and louder, as this GM technology was with a food crop compared to *Bt* cotton (Figure 4). The Government, unfortunately, succumbed to public pressure, and not only did it stop the technology from being commercialised but also announced a ten-year moratorium on all R&D activities related to GMOs (Choudhary et al., 2014). It dealt a big setback to the research and development of GM crops in the country. It also set a bad precedent in not observing the established norms and could be regarded as political interference in the approval process.

India's loss was Bangladesh's gain. The Mahyco Company promoted this technology in neighbouring Bangladesh, and Bt brinjal was approved there for commercial cultivation in 2013. The technology appears to have found ready acceptance in Bangladesh and is estimated to have been adopted by over 27,000 farmers in 2018 (Shelton et al., 2018). There too, there have been some protests against the technology. The green group, Ubinig, alleged that the Government rushed into introducing GM food crops in Bangladesh, and all the prerequisites were not followed adequately (Meenakshi, 2019).

Figure 4 Public protest against Bt brinjal in Bengaluru in 2010. Photo courtesy: BBC

However, a detailed study carried out by the International Food Policy Research Institute (IFPRI) in collaboration with the Bangladesh Agricultural Research Institute and the Department of Agricultural Extension tells a different story (Ahmed et al., 2019).

The study examined the impact of *Bt* brinjal in Bangladesh on production systems, marketability, and health and found that there was a 51% reduction in the number of pesticide applications, 39% reduction in the quantity of pesticides applied, 41% reduction in the toxicity of pesticides applied, as measured by the Pesticide Use Toxicity Score (PUTS) and 56% reduction in environmental toxicity, as measured by the Field Use Environmental Impact Quotient (EIQ-FUR). It was found that the net yields 42% higher with a 31% reduction in the cost of production (most of this was from reduced use of pesticides), an increase of 27.3% in gross revenues and an increase of Tk 33,827 (approximately 400 USD) per ha in net profits.

Reduced application of insecticides also meant lowering the health risk as most farmers do not use protective measures during pesticide application (Rashid, et al.,2008; Dey, 2010). Many in India still feel that it was a wasted opportunity, and the country could have benefitted a great deal with this technology.

Developments post-Bt brinjal

Further to the moratorium on *Bt* brinjal, the Indian Government set up a Parliamentary Standing Committee to assess the impact of GM crops on agriculture and the environment. The report tabled in the *Lok Sabha* on 9 August 2012 raised concern over the potential and actual effects of GM crops on farming, health, and environment, and it concluded that *GM crops are just not the right solution for the country* (Lok Sabha, 2012). It emphasised that the Government should not promote the views of the biotechnology and seed industry. Further, it added that *Bt*-cotton did not improve the socio-economic conditions of the farmers in the country but had led to further deterioration of farming conditions, especially in the rainfed areas.

Meanwhile, following a lawsuit, the Supreme Court of India appointed a five-member Technical Expert Committee (TEC), which also held that GM crops were not suitable for India and recommended an indefinite moratorium on field trials of GM crops and a ban on their commercial release. Realising that the TEC did not have an agricultural scientist, R. S. Paroda (a former Director-General of ICAR) was later included in the Committee, who did not agree with the TEC recommendations. He made it clear to the Court that the report was submitted without his consent and was 'neither transparent nor objective', and presented a separate report recommending the continuation of field trials (Kumar et al., 2014). Meanwhile, the Government took away the GEAC's 'approval' powers and renamed it *Genetic Engineering Appraisal Committee* (GEAC).

GM Mustard

The popular view for the opposition to GMOs by protesters is that the multinational companies pushed the technologies. However, this was proved wrong when a home-grown technology was also equally opposed. This is related to GM mustard (*Brassica juncea* (L) Czern) resistance to the non-selective herbicide glufosinate by Delhi University.

The team, led by Professor Deepak Pental, developed *Dhara* Mustard Hybrid-11 (DMH-11) through genetic manipulation, inducing sterility in an Indian variety as the female parental line, using the gene *barnase* that was derived from a soil bacterium, and crossed it with the male East European variety (Jayaraman, 2017).

The bacterial gene (*'barstar')* was also introduced in the male line to restore fertility in the offspring (DMH-11) so that the farmer gets fully fertile seeds. Additionally, a herbicide-tolerant third gene ('*bar'*), derived from another soil bacterium, was incorporated to identify plants that have been genetically modified. The '*bar'* gene has been introduced only to facilitate hybrid seed production, and the DMH 11 will not be required to be sprayed with herbicide by farmers, as alleged by critics

India is not self-sufficient with oilseed production, importing over 60% of the total requirement. The vegetable oil import is the third biggest import item after crude oil and gold. In 2014-15 India imported 14.6 million tons of edible oil, costing over INR 700 billion (10 billion USD), and it is estimated the imports could reach 20 million tonnes by 2030. The Government is making serious efforts in boosting oilseed output to reduce the import burden (Economic Times, 2021).

In this background, it is difficult to comprehend why the GM mustard developed domestically with a yield advantage of up to 30% was not approved, despite the strong recommendation by the Indian academia (NAAS, 2016). The anti-GM Lobby, however, feared that the approval for GM mustard would open the gate to several GM food crops. Unfortunately, Government gave credence to the unfounded claims of the activists of the risk of having GM elements in food crops. It is insincere because India is already consuming oil derived from GM crops. Choudhary and Gaur (2015) estimated that about 2.5 million tons of oil derived from GM crops are used in India annually -1.5 million tons from domestically grown *Bt* cotton and the remaining 1.0 million ton through GM soybean oil imported from overseas.

The technology was primarily meant to select male sterile female inbred lines that would be helpful in hybrid seed production. The hybrid obtained was not required to be sprayed with herbicide by farmers, as alleged by the critics. Further, it is known that mustard, being a fast canopy-forming plant, is not much affected by weeds, and farmers seldom use herbicides for weed control in the mustard crop. These vital facts, however, could not impress the GMO opponents. This was once again a major setback for scientists engaged in GM research.

I was personally disappointed, as I was also involved in the initial screening of mustard hybrid lines at ICAR-DWR Jabalpur from 2003-05 (Figure 5). The Delhi University took 14 years and reportedly spent INR 700 million (USD 10 million) of public funds to create the hybrid that was expected to increase mustard production and help India reduce its import bill for edible oil did not make sense to the opponents and the Government.

GM Herbicide Tolerant (HT) Crops

Crops with a genetically-engineered (GE) trait conferring herbicide tolerance were among the first biotechnology-derived crops commercialised in agriculture (Huang et al., 2015). The GE trait conferring tolerance to the 'within-crop' application of the herbicide glyphosate was introduced in soybean and canola in 1996 and, in cotton, in 1997, revolutionising agricultural practices for these crops.

Figure 5 GM-mustard, developed at Delhi University, under trial in a containment facility in ICAR-DWR, Jabalpur during 2002-03. GM-mustard (right) and non-GM control (left) treated with herbicide glufosinate

In 1996, biotech corn was introduced that provided tolerance to the herbicide glufosinate. Herbicide glyphosate affects plant growth by inhibiting 5-enolpyruvyl-shikimate-3-phosphate (EPSP) synthase enzyme that is responsible for the biosynthesis of aromatic amino acids. An EPSPS version resistant to glyphosate inhibition isolated from an *Agrobacterium* strain CP4 (CP4 EPSPS) was used to develop crops resistant to glyphosate (Heck et al., 2005; Huang et al., 2015).

The research and development of HT crops in India started back in 2008 with the first imports made by the trait developer company - Monsanto (now, Bayer) through its Indian subsidiary Mahyco of GM-*Bollgard 2* cotton seeds with HT trait (known as event MON 88913) called Round-up Ready Flex (RRF). Subsequently, they imported *Bt* corn, resistant to the shoot and cob borer, stacked with a glyphosate-resistant gene (Choudhary and Gaur, 2015).

Following the approval from the regulatory authorities, containment and open field trials with these GM crops were carried out in several locations for over 4-5 years by the SAUs and ICAR institutes and encouraging results have been reported in peer-reviewed journals (Chinnusamy et al., 2014; Dixit et al., 2016; Sushilkumar et al., 2017; Yadav et al., 2020). All these successful technologies are still awaiting approval from the Indian Government.

The anti-GMO Lobby

There is continuing opposition to GM crops globally. The main arguments being its purported negative impacts on the environment and ecology, concerns on health and safety of GM food of animals and human beings who consume such crops, and the inaccessibility of the GM technologies to small-holder farmers, due to IP protection and unaffordability. I discuss some of these in the following sections, restricting my comments to HTCs only.

Figure 6 Activists and farmers protest against the clearance of GM mustard outside the Ministry of Environment, Forest, and Climate Change in New Delhi. Photo courtesy: *[Outlook]*

GM crops replace labour affecting farmer livelihoods

Manual weeding has been the most predominant method of weed management in the country. Despite limitations, manual weeding has been conducted over decades, or centuries, primarily employing family labour. However, socio-economic conditions in India have changed substantially over the past 70 or so years. The country is currently undergoing rapid transformations, including rapid economic growth. The contribution of agriculture to national GDP has come down to around 18% compared to over 50% in the 1950s, with concomitant decreases in people dependent on agriculture.

Urbanisation and intensification of agriculture and allied activities have resulted in labour shortages with sharp increases in wages. Further, many government schemes are in operation, intending to improve the income and livelihood of under-privileged populations. An employment guarantee scheme (**https://www.nrega.nic.in/**) under which employment for one person in the family for a minimum of100 days a year is guaranteed. The*National Food Security Act* (**https://dfpd.gov.in/nfsa-act.htm**) promises 75% of the rural population and 50% of urban households the right to food. Currently, seven kg of food grains (rice, wheat, and coarse grains) per person per month is distributed at highly subsidised rates of INR 1 to 3 (approximately USD 0.14 to 0.42).

In my view, it is therefore unreasonable to assume that herbicides, in general, and GM crops, in particular, will replace labour and affect rural livelihoods. Weed management accounts for 20-30% of the total cost of crop production, and more and more farmers are using herbicides today as it saves 50-60% of the cost compared to manual weeding (Yaduraju and Mishra, 2018). The use of draught animals for mechanical weeding has also been reducing drastically as buying and maintaining them has become expensive lately.

Weeds consumed by humans and used as feed for animals

The activists argue that herbicides would kill weeds, some of which are used by the rural population as leafy vegetables and fodder for farm animals. It is an exaggeration, as only a few weeds qualify as green vegetables, and only a few are palatable to animals. It is well documented that weeds cause significant yield losses by competing with crop plants for costly inputs such as nutrients and water. It is therefore unscientific to suggest 'cultivation' of weeds. Instead, it makes sense to devote a small portion of land for growing such weeds to meet the farmer's needs.

Development of "Superweeds"

Opponents allege that the pollen of HTCs may cross-fertilise with its wild relatives and create what are dubiously called "superweeds". The inter- or intra-species fertilisation is not uncommon in the plant kingdom. At least 44 cultivated crops have demonstrated the capacity for hybridisation with wild and weedy relatives, including rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L), sorghum (*Sorghum bicolor* Moench), soybean, rapeseed, etc. (Ellstrand, et al., 1999). Gene flow, however, depends on the availability of such species near the area of cultivation (Messeguer, 2003). While reviewing the impact of GM crops in the USA, the report prepared by the *National Academy of Sciences* (NAS) observed that "*Although there has been gene flow from GE crops to wild relatives, no examples have demonstrated an adverse environmental effect*" (NAS, 2016).

It may be risky in rice, for instance, where there are many 'weedy' and 'wild' rice races in some areas in the country. Besides the presence of wild relatives close by, many factors, such as adequate fertilisation, ability to produce viable seeds, the fitness of the progeny to survive etc., contribute to the successful establishment of the hybrid. Crop plants, which are not native to the region, and which are introduced, are unlikely to have wild relatives as weeds and are expected to be least risky. In India, corn, soybean, cotton and to a great extent mustard (the leading crops that have been benefitted by GM technology, globally), besides many other crops, are unlikely to result in any adverse effect on biodiversity in the event of cultivation of their GM counterparts (Deepak Pental, 2021, *pers. comm.*, 6 June 2021).

Impacts on biodiversity

The risks of GM crops for the environment, especially for biodiversity, have been extensively assessed before and during their commercial cultivation. Sanvido et al. (2007) reviewed the scientific knowledge available worldwide from 1996-2006, focusing on commercialised herbicide tolerance (HT) and insect resistance (IR) traits and found no scientific evidence to suggest that the cultivation of commercialised GM crops caused any environmental harm. The HTCs involve non-selective herbicides, and there is a genuine concern about their long-term use on flora and fauna. However, unlike in developed countries, where a single crop is cultivated on vast acreages (i.e. monoculture cropping), the situation in India is different.

Over 75% of the farms are under two hectares, with many farmers planting more than one crop in their fields. Hence, the fear of eliminating all vegetation, including the associated flora and fauna, does not hold. The developers of HTCs are required to submit data on such investigations. Commercial cultivation is approved by the regulating agency only after it is satisfied fully with the data on potential biodiversity impacts (MEF&CC, 2015).

GM food is unsafe

It is a misconception that a foreign gene in GM crops will affect food quality and adversely impact human and animal health. Given the controversies, GM food is subject to more stringent analyses than any other food. Before entering the marketplace, GM food is assessed using guidelines issued by several international scientific agencies, such as the World Health Organization (WHO), Food and Agriculture Organization (FAO) and the Organization for Economic Cooperation and Development (OECD) countries (ISAAA, 2016).

The general conclusion from studies conducted over the past two decades is that GM food is no more likely to cause a human or animal health problem via consumption than the same non-GM food. The aforementioned *National Academy of Sciences* report in 2016 also concluded that: '*Genetically-engineered crops are as safe to eat as their non-GE counterparts, they have no adverse environmental impacts, and they have reduced the use of pesticides*' (NAS, 2016). It may also be acknowledged that millions have been consuming GM food for years with no single adverse effect. It is reported that about 75% of processed foods in the US have GE ingredients.

However, I favour labelling as the consumers will have the right to know what they are consuming. Despite this science-based evidence, the activists are needlessly targeting GM food. It could significantly contribute to society if these activists could take up far more widespread and dangerous issues in India, such as food adulteration.

The threat of herbicide-resistant weeds

Of all the concerns expressed about HT crops, this one is truly significant. The problem of herbicide-resistant weeds is a global one. There are currently 263 species of weeds that have evolved resistance to 23 of the 26 known herbicide sites of action and 164 different herbicides worldwide (Heap, 2021).

Since the cultivation of HT crops, there has been an exponential increase in the use of glyphosate. Although glyphosate belongs to the low-risk category with respect to the development of resistance, many weeds have developed resistance to glyphosate the world over. According to Heap and Duke (2018), 38 weed species in 34 crops from 37 countries have developed resistance.

It is widely acknowledged that overreliance on a single herbicide and its continuous use are the leading causes for the development of resistance in weeds. Besides herbicides, introducing diversity in weed management involving preventive, mechanical and cultural methods of weed control is an effective strategy in managing herbicide-resistant weeds (Owen, 2001; Norsworthy et al., 2012).

The rational use of herbicides with emphasis on herbicide selection, targeting different sites of action, and their use in rotation, are critical factors in herbicide resistance development. However, many farmers tend to ignore these recommendations and rely on cheaper herbicides. In North America, the HR crop technology provided simple, flexible, effective, and economical weed management options to farmers (Jha and Reddy, 2018). This led to the rapid adoption of glyphosate-resistant (GR) soybean, cotton, and corn, often with the sole application of glyphosate over large areas. Its use was accompanied by a drastic decline in mechanical and cultural methods (Green, 2011; Shaw et al., 2009).

Ultimately, overreliance on glyphosate resulted in the evolution of GR weeds. It is an important lesson for other countries, including India, which may introduce HT technology in the future. Adequate preparedness and following strict guidelines, as suggested above, would mitigate the problem significantly.

The Scientific Community responds

The scientific community in India did not accept the negative campaigning carried out by the anti-GM Lobby and the unscientific decisions the Government took in curbing the research and development of GM crops. Following the moratorium declared by the Government, the *National Academy of Agricultural Sciences* (NAAS) recommended that it is high time to approve the environmental release of the GE varieties, which have been proven to be bio-safe. Highlighting the benefits of these crop varieties, the NAAS report advised their release to farmers and consumers without further delay (NAAS, 2016).

A group of top 17 agricultural scientists in India then produced a paper arguing in favour of GM technology, stressing the need for ensuring food and nutrition security in the country (Datta et al., 2019). They have referred to many reports prepared by the reputed global academia and research papers published in peer-reviewed journals to support positive outcomes of GM crops.

The conservative European Commission in its 2010 report also stated: '*The main conclusion to be drawn from the efforts of more than 130 research projects, covering a period of more than 25 years of research and involving more than 500 independent research groups, is that biotechnology, and in particular GMOs, are not per se riskier than conventional plant breeding technologies'* (European Commission, 2010).

Datta et al. (2019) chastise anti-GMO campaigns as scientifically baseless and potentially harmful to poor people in the developing world. They argue that the perception carried by anti-GM groups is at variance with the consensus arrived at by significant science academies of the world[7]. Referring to many publications in credible, peer-reviewed journals, Datta et al. (2019) support their pro-GMOs stand. For instance, 147 original studies based on primary data from farm surveys anywhere in the world reporting the impact of GM soybean, maize or cotton on crop yields, pesticide use, and farm profits have shown that, on average, GM technology adoption has reduced pesticide use by 37% increased crop yields by 22% and increased farmer profits by 68%.

An extensive study carried out by the US National Academies of Sciences, Engineering, and Medicine comprising of eminent members from all relevant disciplines and after interacting with domain experts from different countries, reviewing hundreds of peer-reviewed publications have concluded that the GE crops had no adverse environmental impact, had reduced the use of pesticides and the GE food was as safe to eat as their non-GE counterparts (NAS, 2016).

Soon after the moratorium on GMOs was declared, the *National Academy of Agricultural Sciences* (NAAS) organised a Round Table on 14 February 2014 to discuss the future course of action. Held under the Chairmanship of M. S. Swaminathan, it stressed the potential and relevance of research on GM technology in meeting the food and nutritional security of India. It made several recommendations, the important ones being (a) lift the embargo on controlled field trials on GM crops, (b) approve the environmental release of the GE varieties, which have been proven bio-safe, and (c) drop the requirement of obtaining '*No Objection Certificates*' from the States for field trials (NAAS, 2016).

The ICAR-DWR and the ISWS held three discussions over five years involving different stakeholders. They, too, unequivocally supported the new technology and appealed for the withdrawal of the moratorium. Responding to the criticisms aimed at scientists, Datta et al. (2019) rightly observed that:

> *"…While there is always scope for improvement in any institution, indictment of the regulatory bodies is an insult to the integrity of a large body of scientists who have toiled*

[7] The Agencies and Organizations include the US National Academy of Sciences, American Association for the Advancement of Science, The Royal Society (UK), African Academy of Sciences, European Academies of Science Advisory Council, the French Academy of Science, American Medical Association, Union of German Academies of Science and Humanities, Indian National Science Academy, and others.

hard for years to monitor the trials and be part of the approval process…".

Datta et al. (2019) quoted the support of 107 Nobel laureates, who in 2016 appealed to *Greenpeace,* an environmental organisation, to rethink its long-standing opposition to GMOs. The industry also voiced their concern, time and again, about the lack of interest and slowness on the part of the Government in promoting the technology (Jayaraman, 2012). The leading media houses have also been supporting the GM technology by publishing informative and balanced views on issues related to GMOs, to no avail.

While the public and the political leadership recognise the contribution of agricultural scientists in transforming India from a 'food-deficit' to a 'food surplus country, it is disappointing that on GM crops, the voice of science is not well heard. This will surely discourage and dampen the interest and enthusiasm of the scientific community in India and scuttle future innovation.

The dithering Government Response

It was hoped that the new *National Democratic Alliance* (NDA) Government, which came to power in 2014, would take a different approach. The interest to change the course on GM field testing was evident when the regulatory authorities allowed field trials of few GM crops, including HT crops, in 2014 (Kumar, 2015). More than 20 crops underwent various research and field trials for genetic modification. Eight Indian states aligned with NDA have approved field trials of GM crops, between them allowing tests that include transgenic rice, cotton, maize (corn), mustard, brinjal and chickpea (*Cicer arietinum* L)

The new Government was considered more proactive in promoting modern technologies. The Government has an ambitious program of doubling farmers income by 2025 through modernising agriculture and creating an enabling policy environment. However, the Government did not have a road map for taking GMOs forward. Its reluctance to engage in transparent debates about the pros and cons of GM biotechnology aggravated the situation. The details of the meetings of the *Genetic Engineering Appraisal Committee* (GEAC) that used to be publicly posted on its website no longer appear on-line now. The GEAC approved the commercial cultivation of GM mustard, developed by the Delhi University, in May 2017. Still, the Ministry of Environment and Forests did not act while facing powerful opposition from the anti-GM Lobby (Indian Express, 2017).

The NDA government, even after re-election with a better majority in 2019, has not taken GM technology seriously. This is reflected in the establishment of the much-awaited Biotechnology Regulatory Authority of India (BRAI) is yet to take wings. BRAI, as an autonomous statutory agency conceptualised in 2008, was intended to provide a single-window system for transparent and quick clearance of proposals related to biotechnology, including GMOs. Despite several revisions, the BRAI bill is yet to be re-introduced in Parliament.

These developments have not instilled confidence in the industry. Many multinational biotech/seed companies, who at one time were seriously pursuing their efforts in commercialising GM crops, are disappointed with the Government's apathy and are curtailing their products and scaling back investments. The Dow-Dupont deferred the Biosafety Research Level-1 field trials with transgenic insecticide-resistant and herbicide-tolerant GM corn planned during 2018 [8].

Monsanto, now a unit of Bayer AG stung by a series of unfavourable government decisions, withdrew an application in 2016 seeking approval for next-generation GM cotton seeds. The insect resistance and herbicide (glyphosate) tolerance of corn and cotton projects, promoted by Bayer AG, and tolerance of corn, promoted by Corteva, have been put on hold since 2016. The GM seeds have also been subject to litigation for some time in India concerning intellectual property issues. The Delhi High Court barred Monsanto from claiming patents on its GM cotton seeds in 2018. The appeal made in the Supreme Court has also been turned down[9]. The domestic seed companies have welcomed the news as they will no longer be required to pay the hefty licence fee to Monsanto.

On the contrary, the multinational seed companies are disappointed as they feel deprived of protection for their innovation. This will be a massive loss to the country as it will not be able to access modern technologies that are needed for further strengthening of food and nutritional security of the country and for promoting sustainable agriculture.

[8] Source: **http://news.agrompages.com/newsDetail-27162.htm**.

[9] Source: **https://www.ifoam.bio/en/news/2018/05/08/indian-supreme-court-says-seeds-plants-and-animals-are-not-patentable**)

The regulatory system in India

The introduction, testing and release of GMOs in India is governed by a well-drawn out the regulatory procedure through six competent authorities but administered under three different Ministries (MEF&CC, 2015). Rules1989 regulates the regulation of all activities related to GMOs and products derived from GMOs under the provisions of the *Environment Protection Act* (EPA), 1986. The information requirement concerning the safety assessment of GE plants covers GM on protein characterisation, food and feed safety, environmental safety including weediness and aggressive potential, impact on non-target and beneficial organisms, gene flow and crossability studies. The issues are discussed on a case-to-case basis, and the whole idea is to minimise the adverse impact that GMOs and products thereof would have on the environment and human and animal health. GEAC, the highest statutory body in the regulatory system, has powers to revoke approvals in case of new information of harmful effects or non-compliance of stipulated conditions.

While chronicling the history of the regulatory system in India, Choudhary et al. (2014) pointed out three fundamental flaws in the EPA Rules 1989 that need to be rectified. Firstly, GM crops are categorised as 'inherently harmful' under the 'hazardous substance' provision of the *Environmental Protection Act* 1986, which is scientifically incorrect and gives rise to misperceptions about the safety and potential risk of GM crops. Secondly, the EPA Rules 1989 to regulate GM crops were issued not by a 'legislative act' but by an 'administrative order' that remains untenable and liable to change with the discretion of the Environment Ministry, which affects the predictability of the regulations and ignores the need to take into account the views and policies of other concerned ministries.

Finally, the Union Environment Ministry administers the regulation of GM crops in India, whereas agriculture falls under the respective State(s). This often confronts approvals posing a 'Union Vs State' conflict in decision-making on GM crops. Such changes, if made, I am sure will make the regulatory system robust, effective, and sustainable. 'Conflict of Interest' is another commonly quoted criticism, which is not difficult to handle.

The illegal cultivation of HTBt cotton

The absence of a National Policy on GM crops and the Government's indecisiveness has led to a serious and problematic situation. The country is witnessing large-scale illegal cultivation of HTBt cotton. Stared in 2015, the area is increasing with each passing year and has been covered in the media regularly (Times of India, 2020).

Responding in the *Loksabha*, the Lower House of the Indian Parliament, the Agriculture Minister, admitted to the illegal cultivation of HTBt cotton in Maharashtra, Telangana and Gujarat, and the various actions to prevent it (Times of India, 2019). A high-level expert panel, the Field Inspection and Scientific Evaluation Committee (FISEC), set up by the Prime Minister's Office under the Department of Biotechnology to probe illegal HTBt cotton markets in 2018, has estimated the share of the illegal HTBt cotton crop to be 15% of the total cropped area (Hindustan Times, 2020).

Farmers experience a yield reduction of over 20% in cotton due to inadequate weed control (Gharde and Singh, 2018). Weed management, normally achieved through manual and mechanical approaches, constitutes about 30% of the total cost of crop production. Due to scarcity of labour, farmers find planting HTBt cotton and glyphosate for controlling weeds is convenient and economical. This is the primary reason for the growing popularity of HTBt cotton and the farmers’ open defiance for planting illegal cotton seeds.

In four districts of Maharashtra, close to 90% of the cotton grown was under illegal HTBt in 2019, as per *Shetkari Sangathana*- a powerful farmers union in Maharashtra (Financial Express, 2019). *Shetakari Sangathana*, a non-political Union of Farmers, formed to have "*Freedom of access to markets and Technology*" is spearheading the pro-GM crop agitation throughout the country. The Union has accused the Government of denying HTBt technology that has been proved helpful to farmers.

Defying the Government ban, the Union distributed GM seeds of soybean, maize and brinjal to farmers willing to sow the crop (Figure 7). It has also joined hands with farmer's groups in other states to distribute GM crops seeds to farmers. I see this as a contradiction to the argument made by the GM activists that farmers do not want GM technology.

***Figure 7** Farmers on protest demanding access to HTBt cotton. To a call given by Shetkari Sangatana– over 2000 farmers broke the law and planted GM cotton at Akoli Jahangir village, Maharashtra, on 10 June 2019. Photo courtesy: Firstpost*

For the record, the Government is 'taking action' by booking cases against errant farmers, confiscating seeds etc., but on the ground, I feel nothing much has changed or likely to change soon.

The cotton seed trade accounts for over INR 250 million (USD 3.3 million) per annum and is threatened by the illegal trade of unapproved seeds (The Hindu, 2020). With the huge carry-over of unsold seeds in the 2020 season, the industry is worried over the illegal sale of GM cotton seed, estimated at over 5 million packets (of 450 gm each) in the 2021 season. The seed companies are also urging the Government to act fast.

The anti-GM protesters are mainly silent but for few token comments. The criticisms made by the GM activists of the negative impacts of GM crops on the environment and biodiversity look hollow. It is pertinent to recall a similar large scale illegal cultivation of *Bt* cotton in the country before it was officially approved in 2002 (Jayaraman, 2001). This unlawful and unapproved cultivation, many believe, was the main reason for finally approving the first GM crop in the country. A similar situation could arise with illegally-grown HTBt cotton as well.

Glyphosate targeted

In India, it appears that the situation of illegal cultivation of HT *Bt* cotton is out of control. The anti-GM groups point to a 'regulatory failure', blaming the authorities for their apathy and incompetence in tackling the problem. Unable to confront the two sides - agitating farmers and the protesting activists, the Government issued a draft notification in July 2020, restricting the use of the popular herbicide glyphosate (Economic Times, 2020).

The Government wants to curb the menace of HTBt cotton by restricting the availability of glyphosate. According to the notification, the herbicide application will be allowed only through registered pest control operators, who are almost non-existent in rural areas. The move has been strongly criticised by the farmers, farmer organisations, the industry and academia. Presently, an expert committee is looking at these representations, and its recommendations are eagerly awaited.

It is a desperate attempt, albeit an indirect one, to discourage the cultivation of HT cotton. I feel that this will do more harm than good. The herbicide glyphosate is popular with farmers. It is widely used for weed management in non-crop areas, as a pre-till treatment particularly under conservation agriculture and as a directed spray in broadly spaced crops such as cotton, sugarcane, orchards, and plantation crops. Among the herbicides, glyphosate (with about 14.25 million kg use annually) is the largest selling one, with a 37% share (Brooks, 2019).

Application of glyphosate at low doses is also recommended to control the parasitic weed broomrape (*Orobanche aegyptiaca* Pers.) - a severe problem in mustard in the north-west part of India (Punia, 2014). Brookes (2019) examined the farm-level implications of restrictions on glyphosate use. According to him, besides the non-adoption of GM HT crops, the impacts are likely to be higher weed control costs, low levels of weed control, increased incidence of pests, lower yields and loss of benefits associated with no-tillage.

Meanwhile, the classification of glyphosate as "*probably carcinogenic in humans*" (category 2A) by the *International Agency for Research on Cancer* (IARC) of WHO has added fuel to the fire. At least a few States in India have joined some developed countries in either restricting or banning the use of glyphosate without any detailed scientific discussion on the issue. The IARC's findings have given new ammunition to the anti-GM Lobby, who have intensified their demand not only for the banning of GM crops but also for banning all pesticides, including glyphosate. However, the findings are being contested and warrant detailed scientific scrutiny.

Farmers in India are desperately in need of promising technologies for the management of weeds. The increasing cost of manual weeding and mechanical weeding through draught animals forces farmers to look for alternatives. Mechanical weed control with available hand-drawn tools is not suitable under all soil and climatic conditions. The tractor-drawn machines have limited use, as over 75% of the farmers are either small or marginal with less than two-hectare land. Small power operated weeders are making an entry and will take some time to find popularity. Meanwhile, farmers are experimenting with various local innovations to manage weeds. There are weeders drawn by bicycles or motorbikes.

What is more striking is the innovations made in the use of glyphosate. Glyphosate is applied between crop rows protecting the crop from direct contact with the herbicide (Figure 8). The crops are covered with plastic buckets (in case of broadly spaced crops, such as watermelons, cucurbits), cloth or plastic screens (held manually or drawn mechanically) on either side of the crop row (tomatoes or cotton) (Figure 9).

***Figure 8** Directed application of herbicide glyphosate in cotton using a plastic hood attached to the spray lance. Farmers prefer herbicides as manual weeding is 2-3 times more expensive*

***Figure 9** Inter-row application of glyphosate in cotton crop. The cloth/plastic screens are used to protect the crop from herbicide injury*

More 'advanced' application techniques involve a portable system (drawn by either bullocks or tractors). Here, inverted cut PVC pipes of a certain length with cloth/plastic screens in the sides to cover, say 4-5 crop rows, are drawn by a pair of bullocks and a person walking between the screens applying the herbicide manually. The photos and videos of such innovations have been making rounds on social media. All these point to the fact that farmers are well aware of the efficacy of glyphosate in controlling the weeds, and they are going to extremes to protect the crop from herbicide injury.

These attempts by the farmers underscore the need for technology, such as the use of HTCs to manage weeds without worrying about crop safety. The large-scale adoption of HT *Bt* cotton by farmers in open defiance of the Government's ban is a testimony of their approval of HT technology. Keeping the farmer's interest in view, the Government should lift the ban on GM HT crops and remove proposed restrictions on the use of glyphosate.

Conclusions

Based on the examination of issues related to India and surveys of global literature, I believe that the GE crops can benefit farmers in India. The HT crops, in particular, could substantially reduce the cost of weed management, which accounts for a whopping 20-25% of the total costs of cultivation. It is evident that since their introduction in 1996, GM crops neither had any noticeable negative impacts on the environment nor the health of humans and animals in countries that have been growing these GM crops for many years (see NAS, 2016).

On the negative side, continuous cultivation of HT crops has probably led to the resurgence of herbicide resistance in several weeds. However, learning from the mistakes made by some of these countries, the negative impacts of herbicide-based technologies could be significantly reduced by introducing diversity in weed management involving different methods, with particular emphasis on crop rotation, herbicide rotation and herbicide mixtures.

Currently, in India, genetically engineered cotton and maize have undergone multi-location open field trials and are waiting for over five years for the final approval by the GEAC (Chinnusamy, et al., 2014; Dixit, et al., 2016; Sushilkumar, et al., 2017; Yadav, et al., 2020). After the approval by the GEAC for open cultivation, the GM mustard is awaiting clearance by the Minister of MOEF&CC, and It is time for the Government to act fast and decisively to provide access to these technologies to benefit the farmers.

The large-scale illegal cultivations of HTBt cotton in several Indian States cannot be ignored any longer. The Government's approval for HTBt cotton will formalise illegal planting, benefit more farmers in adopting the technology and legitimise seed trade by eliminating unscrupulous traders.

The GM crops, since their introduction in 1996, are currently being planted on over 190 million hectares in 29 countries, including 24 developing economies (ISAAA, 2019). Further, 43 more countries are importing and consuming GM crops/products as food or animal feed. The accumulated GM crop area from 1996 to 2019 was 2.7 billion hectares, with an earned (1996-2018) economic benefits of USD 229.4 billion to 18 million farmers and their families, 95% of whom were small farmers. It is time for India to take advantage of the challenges and experiences the countries faced in commercialising GM crops to help itself move forward decisively.

As discussed earlier, the review of the vast amount of data indicated no evidence to suspect the safety of food and feed derived from GM crops and the negative impact they may have on the environment, including biodiversity (NAS, 2016; Sanvido, et al.,2007).

The Government should stand firm and not yield to the false propaganda unleashed by the GM activists. Instead, it should believe in science and repose trust in scientists and value their expert advice. It is a dangerous trend to allow a small group of activists to hold the country to ransom.

I hope that the Government will establish the much-anticipated Biotechnology Regulatory Authority of India (BRAI) after incorporating the desired changes that will act as a single-window facility and a clearing house for the proposals in a time-bound manner. Professionalism, transparency, and integrity in its functioning will instil confidence in all the stakeholders, particularly the activists and the public.

All the vital data and facts related to GM technology should be made available publicly and shared appropriately with all stakeholders. It is essential to develop an effective communication strategy with the public in sensitising and creating awareness of the new technologies.

Engaging the public intensely from the beginning will allay misjudged fears and apprehensions. Such activities will help prevent embarrassing and unpleasant situations that may occur at a later time. Further, the Government should also take a stand on intellectual property (IP) rights for genetically modified 'traits', which is not clear. The lack of IP protection scuttles innovation, access to new technologies and harms investments in the country.

The debate for and against GM crops may not end quickly. I am aware that GM crops may not be a panacea, but they have the potential for benefiting farmers and in achieving food and nutritional security targets. Like any technology, GM technology too has some risks. However, I feel that the benefits far outweigh the risks associated with them. While I was concluding this essay, there comes the news that the Government has stalled its decision of allowing scientific field trials of transgenic crops, including indigenously developed *Bt* brinjal (Times of India, 2021a). This was disclosed by the Environment Minister’s written response to a Parliament question in *Rajya Sabha* (Upper House) on 22 March 2021.

This turnaround comes after the central regulator, GEAC, had in 2020 allowed bio-safety research field trials of two new transgenic varieties of *Bt* brinjal in eight States during 2020-23. According to the media reports, this has been done under pressure from *Bhartiya Kisan Sangh* (a fringe body associated with the NDA Government) and heeding to the unwillingness of some States to issue '*No Objection Certificate*s' (NOC) for biosafety field trials. Ironically, the same day, in response to another question, the Minister made the following positive comment on *Bt* cotton: "*Long-term studies conducted by Indian Council of Agricultural Research on the impact of Bt cotton cultivating states has not reported any adverse effect on soil, microflora and animal health*".

This exposes the Government's predicament on this issue. Their action has received widespread criticism in the media, including a piece in the editorial of a leading daily (Times of India, 2021b). The on-going farmer's protest following the introduction of the *Farm Reforms Ac*t in September 2020 has attracted global attention (Wikipedia, 2021). During this standoff, it is unlikely that the Government will antagonise farmers and their supporters yet again by supporting GM technology anytime soon. Copying the famous quote, "*The King is dead, long live the King"*, would it be appropriate to say: "*The GM crops are dead, long live GM crops?"*. Only time will answer this question.

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Common and chemical names of herbicides used in this paper:

Common name	Chemical name
Chlortoluron	*N*'-(3-chloro-4-methylphenyl)-*N*,*N*-dimethylurea
Clodinafop	(R)-2-[4-[(5-chloro-3-fluoro-2-pyridinyl)oxy]phenoxy]propanoic acid
Fluazifop-p-butyl	(R)-2-[4-[[5-(trifluoromethyl)-2-pyridinyl]oxy]phenoxy]propanoic acid
Iodosulfuron	4-iodo-2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl) amino] carbonyl] amino]sulfonyl]benzoic acid
Isoproturon	*N,N*-dimethyl- *N*'-[4-(1-methylethyl)phenyl]urea
Glufosinate	2-amino-4-(hydroxy-methyl-phosphinyl) butanoic acid
Glyphosate	*N*-(phosphonomethyl) glycine
Methbenzthiazuron	1-(1,3-benzothiazol-2-yl)1,3- dimethylurea.
Metoxuron	*N*'-(3-chloro-4-methoxyphenyl)-*N*,*N*-dimethyl urea
Metribuzin	4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4H)-one
Mesosulfuron	2-[[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]-4-[[(methylsulfonyl) amino] methyl] benzoic acid
Metsulfuron-methyl	2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]benzoic acid
Pendimethalin	*N*-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine
Pinoxadem	8-(2,6-diethyl-4-methylphenyl)-1,2,4,5-tetrahydro-7-oxo-7H-pyrazolo[1,2-d][1,4,5] oxadiazepin-9-yl 2,2-dimethylpropanoate
Pyroxasulfone	3-[[5-(difluoromethoxy)-1-methyl-3-(trifluoromethyl)pyrazol-4-yl]methylsulfonyl]-5,5-dimethyl-4H-1,2-oxazole
Sulfosulfuron	*N*-[[(4,6-dimethoxy-2-pyrimidinyl)amino] carbonyl]-2-(ethyl sulfonyl) imidazol [1,2-a]pyridine-3-sulfonamide